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ABSTRACT

This document describes NASA's Earth Science Enterprise, a comprehensive program to study the earth as an environmental system. The Earth Science Enterprise has three main components: (1) a series of earth-observing satellites; (2) an advanced data system; and (3) teams of scientists who will study the data. Contents include: (1) "The Earth Science Enterprise," an overview of the program; (2) "Questions and Answers," key questions about how NASA studies the earth; (3) "NASA Facts," information on related science issues; (4) "Earth Science Enterprise Accomplishments," accomplishments from the past to the future; (5) "Earth Science Enterprise Researchers," information about the people who are part of the program; (6) "Earth Science Enterprise Facts," specific information about missions and recent changes; and (7) "Where Do I Get More Information?" a listing of Earth Science Enterprise education contacts. (CCM)

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UNDERSTANDING OUR CHANGING PLANET

NASA'S EARTH SCIENCE ENTERPRISE



1998 Fact Book

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For more information about NASA's Earth Science Enterprise:

Earth Science Enterprise

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Earth Science Enterprise

Since its creation in 1958, NASA has been studying the Earth and its changing environment by observing the atmosphere, oceans, land, ice, and snow, and their influence on climate and weather. We now realize that the key to gaining a better understanding of the global environment is exploring how the Earth's systems of air, land, water, and life interact with each other. This approach—called Earth System Science—blends together fields like meteorology, oceanography, biology, and atmospheric science.

In 1991, NASA launched a more comprehensive program to study the Earth as an environmental system, now called the Earth Science Enterprise. By using satellites and other tools to intensively study the Earth, we hope to expand our understanding of how natural processes affect us, and how we might be affecting them. Such studies will yield improved weather forecasts, tools for managing agriculture and forests, information for fishermen and local planners, and, eventually, the ability to predict how the climate will change in the future.

The Earth Science Enterprise has three main components: a series of Earth-observing satellites, an advanced data system, and teams of scientists who will study the data. Key areas of study include

clouds; water and energy cycles; oceans; chemistry of the atmosphere; land surface; water and ecosystem processes; glaciers and polar ice sheets; and the solid Earth.

Phase I of the Earth Science Enterprise has been comprised of focused, free-flying satellites, Space Shuttle missions, and various airborne and ground-based studies. Phase II begins this year with the launch of the first Earth Observing System (EOS) satellite. EOS is the first observing system to offer integrated measurements of the Earth's processes and will generate a long term environmental database focusing on climate change. We have initiated an era of unprecedented observational capability for understanding the planet.

Just as the first weather and communications satellites fundamentally changed our way of thinking about those fields, so the elements of the Earth Science Enterprise will expand our perspective of the global environment and climate. Working together with our partners around the world, we are well on our way to improving our knowledge of the Earth and using that knowledge to the benefit of all humanity.

- ♦ *SCIENTIFIC STUDY OF EARTH YIELDS NEW KNOWLEDGE AND PRACTICAL BENEFITS*
- ♦ *A SOLID RESEARCH PROGRAM IS UNDERWAY TO ANSWER THE MOST IMPORTANT QUESTIONS*
- ♦ *NASA'S UNIQUE RESEARCH CONTRIBUTION IS THE GLOBAL PERSPECTIVE FROM SPACE*
- ♦ *AN EVOLUTIONARY IMPLEMENTATION APPROACH YIELDS "BEST-VALUE" SCIENCE*
- ♦ *INTERNATIONAL, INTERAGENCY, AND COMMERCIAL PARTNERSHIPS MULTIPLY OUR EFFORTS*
- ♦ *NASA SCIENCE IS PRODUCING VALUABLE RESULTS—BUT THE BEST IS YET TO COME*

How will studying the Earth benefit humanity?

Earth's environment is constantly changing and those changes affect us all. Some of these changes, like tornadoes and hurricanes, are rapid and violent. Other events, like earthquakes and volcanic eruptions, occur suddenly but are the result of pressures in the Earth's crust which have been building for many years. Our climate can change over decades, centuries, and even millennia (the last ice age was one such change). More immediate effects of a changing climate can be seen in altered weather patterns. African nations are concerned about severe droughts, while those in Southeast Asia desire to know with more precision about the arrival of the monsoon. The U.S. is concerned with the likelihood of floods along the Mississippi River, rainfall patterns over agricultural areas, and damaging storms along our heavily populated coastlines. Our current lack of understanding of these changes and their causes impairs our ability to respond.

Environmental changes can be costly to society. Concerns about the Earth reach beyond the scientific community to the business world. Natural disasters cost the U.S. tens of billions of dollars each year. The trillion dollar banking and insurance industries are beginning to see the value of Earth observation in such areas as forecasting severe storms and predicting long-term climate. Such businesses are built on a stable world climate and their well being depends on good information about the future of the Earth's environment. Economic consequences to farmers and others from changing weather patterns and land-use practices are already occurring. Instead of being held captive to whatever climate changes may occur over time, NASA and its partners are striving to discover climate patterns that will allow us to predict and perhaps respond to environmental changes well in advance of their occurrence.

- ◆ Environmental understanding helps us use resources wisely. In order to detect healthy vegetation, farmers, commodity traders, and

insurers will soon be able to use indices of crop conditions derived from satellite measurements of plant "greenness."

- ◆ NASA data is being used to demonstrate the beneficial effects of urban forests which lessen the impact of "urban heat islands," bubble-like accumulations of hot air that have developed as cities have grown during the past 20 years.
- ◆ Sport and commercial fishing fleets are using NASA data to more efficiently locate areas with the best fishing potential, such as locations with certain temperatures and water clarity characteristics.
- ◆ With help from NASA science data, solar power is being provided cheaply and efficiently for people of the world without electricity who often spend the entire day searching for fuel.
- ◆ In 1996, 88,000 wildfires burned over 6 million acres at a cost of over \$1 billion in fire control activities. NASA data has been used to develop a series of fire potential maps in the western U.S. to assist firefighters in fire planning and assessment.
- ◆ Municipalities across the country will soon be able to manage their tax mapping and building permit process by comparing current digital aerial photography and high resolution satellite imagery with that from prior years, using sophisticated computer "change detection" software.
- ◆ NASA data is being used to create "Nowcast" weather forecasts to assist drilling in the Gulf of Mexico. Drilling activities cannot proceed in currents stronger than 2 knots, because of the difficulty in dynamic position-keeping as well as the stresses imposed on the drill itself as it extends through the water column. Accurate, localized weather forecasting reduces the cost of drilling operations.

What do we need to understand?

The Earth is an incredibly complex planet. Many interactions between the Earth's systems of air, water, land, and life remain clouded in uncertainty, and data on some of Earth's processes are sparse. Lacking this knowledge, we are unable to explain why major climate events occur, how often, or where they will strike. Understanding these environmental changes may help us predict when they will occur and how they will affect us, and perhaps enable us to adapt.

Humanity is capable of affecting the planet. As Earth's population grows and economic activity expands, our ability to cause global scale changes in the environment increases. While we do not know precisely how this expansion will affect the global environment, it could lead to environmental changes of a global or regional nature as we have already seen with the upper atmospheric ozone depletion. NASA and its partners will observe and analyze the cumulative consequences of global climate changes.

We must figure out how everything is linked together. The key to gaining a better understanding of the global environment is exploring how the Earth's systems of air, land, water, and life interact with each other. This approach—called Earth System Science—blends together fields such as meteorology, oceanography, atmospheric science, and biology. It is in interactions among the Earth's systems that our base of knowledge is most limited.

Laying the groundwork for further study. Scientists studying the Earth's environment began working together more than a dozen years ago—before the Earth Science Enterprise program started—to better understand and predict climate change and its consequences. We have collected

data, made surprising discoveries, and begun to unravel mysteries of the global environment. But this is just the beginning. We need to collect sufficiently accurate data about the climate system as a whole, so that we can develop reliable projections to tell us how particular regions might be affected.

The Government has a coordinated research program. Recognizing the need for timely, accurate information, the U.S. is carrying out a comprehensive initiative to better understand Earth. This program—called the U.S. Global Change Research Program—is a closely coordinated effort among a dozen Federal agencies that have a unique expertise in studying the Earth. NASA is a leader in these research efforts, with a coordinated program emphasizing land cover and land use change, seasonal-to-interannual climate, natural hazards, long-term climate variability, and atmospheric ozone.

This long-term research has many practical, near-term benefits. Studying the climate yields more than just good science. Farmers, foresters, fishermen, business people, and educators will be able to use the information from this initiative to improve their productivity and competitiveness.

We will learn as we go. It is likely that there are factors involved in climate change, or its effects on the environment and human choices, that we will only discover as our understanding evolves. Having this information will enable informed and objective discussion about the future of the planet, potential global changes, and options for public and private sector actions.

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Why is NASA involved in studying the Earth?

The best way to study the Earth as a whole is from space. From space we can observe global ocean circulation. We can track the transport of dust from Africa's Sahara desert to South America's Amazon rainforests. The global view from space enables scientists to study Earth system processes over large uninhabited areas—the oceans, great deserts, and the polar regions. Events in these regions affect the populated areas of the Earth, and we use observations of the whole planet to build computer models to describe what's happening. Satellites provide the required continuous, global, long-term observations.

NASA is focusing its science and technology expertise toward our home planet. NASA has the experience to do the job. Going back to NASA's inception in 1958, we have developed the expertise in space research and development needed to make the precise measurements that enable scientists to generate reliable discoveries about the environment. While pre-Earth Observing System (EOS) missions have produced exceptional results, EOS will be the first satellite system capable of making comprehensive measurements required for the study of global climate change, perhaps enabling such predictions as regional rainfall a season or a year in advance.

NASA is uniquely suited to lead this international scientific effort. NASA brings to bear an integrated program of space, air, and ground-based observing capabilities, data management systems, and science, offering the potential for a well coordinated research and observation capability. The nations of the world look to the United States for leadership in the development of precise measurements and high quality research that will lead to greater knowledge of the Earth system, practical benefits, and sound policy decisions for the next century.

We are addressing the most important science priorities. NASA worked with university, government, and industry scientists, in such forums as the National Academy of Sciences, to identify the following as areas of maturing science with substantial societal benefits:

- ◆ **Land Cover Change and Land Use Change:** Observing how land and coastal regions are changing over time due to both natural and human activities.
- ◆ **Seasonal-to-Interannual Climate Variability and Prediction:** Learning how to forecast precipitation and other variables a season or a year in advance, with enormous potential payoff for agricultural planning.
- ◆ **Natural Hazards Research and Applications:** Using these same capabilities to project probabilities of floods and droughts in key regions of the nation and the world.
- ◆ **Long-Term Climate Variability:** Building models of climate change that extend annual prediction capabilities to decadal and centennial time frames, and to sort out the natural from the human-induced drivers of climate change.
- ◆ **Atmospheric Ozone:** Extending our base of knowledge on upper atmosphere ozone depletion and recovery to help identify substitutes for harmful chemicals, and beginning to monitor lower atmosphere ozone which is toxic to most life.

How will NASA get this important information?

Ongoing and future missions enable understanding of key Earth system processes. Current satellite and aircraft research efforts are advancing our knowledge of specific environmental processes.

Last year, we launched the Tropical Rainfall Measuring Mission (TRMM), a joint U.S./Japanese mission producing precise measurements of rainfall in the tropics, which is a critical indicator in climate patterns throughout the world. In addition, a private company launched Orbcomm-2 (formerly SeaStar) last year, a spacecraft that is providing NASA with scientific data on life in the oceans—data which is likely to be marketable to the fishing, oil, and shipping industries. Scheduled for launch this year is QuikScat, a mission designed to collect wind-speed and wind direction across 90 percent of the Earth's ice-free oceans every day.

This year the Earth Observing System (EOS) begins the first integrated measurements of changes in global climate and also provides practical information for business, farming, forestry, and fishing. EOS is the first comprehensive system designed specifically to study the Earth as a complex series of interactions between life, air, water, and land. Over the next few years, EOS satellites and complementary international missions will fly over most of the Earth's surface gathering data such as global changes in the atmosphere, land surface, pollution, and water resources. What were once studied as isolated events will be examined as interconnected and interactive forces which form a comprehensive snapshot of the Earth as a whole.

NASA has developed a comprehensive data system to make information readily available. The Earth Observing System Data and Information System (EOSDIS) is designed to relay large amounts of information to scientists, educators, governments, businesses, and the general public. Through EOSDIS, any data set can be accessed via the Internet and other means by thousands of users at the same time throughout the world. EOSDIS data

are directly contributing to the establishment of a national spatial data infrastructure.

NASA has always been at the forefront of developing new technology and new approaches, and the Earth Science Enterprise is no exception. The New Millennium Program (NMP), a coordinated NASA/private industry activity designed to demonstrate next generation technologies such as lightweight, low-cost instruments, will help us reduce future mission costs. NASA selected an advanced land imager as the first NMP mission, scheduled for flight in 1999. Our Earth System Science Pathfinder (ESSP) Program will capitalize on existing technologies using a series of small, rapid-development missions to address unfolding areas of science not covered by EOS. Two ESSP missions have been selected, and the first one scheduled for launch in 2000 will study the distribution of forests. In another innovative program, we are partnering with industry to obtain scientific data more quickly and less expensively—from commercial sources.

NASA has embraced a philosophy of continual, orderly evolution, incorporating new technologies and creating new partnerships to drive down the costs of continuous, long-term measurements. Near-term EOS costs (through 2000) have already been reduced from \$17 billion to \$6.5 billion since 1990. We are vigorously pursuing technology innovations to decrease future costs 30% (after 2000)—saving the U.S. taxpayer billions of dollars. We initiated a Biennial Review of the program last year which has proven to be our most significant vehicle for evolution of the Earth Science Enterprise through careful consideration of scientific, technological, and mission changes recommended by our scientific, international, and business partners.

Why is a broad-based research effort critical to success?

Improving our understanding of the Earth system is a global challenge and the United States cannot accomplish this type of comprehensive research task alone.

In addition to extensive cooperation with other federal agencies through the USGCRP, NASA is working with partner organizations around the world to address this global challenge. International cooperation, usually documented by international agreements, allows NASA to more than double its investment in Earth Science. Through the Earth Science Enterprise's Phase I and the first EOS series, other nations are investing over \$4 billion in NASA's Earth Science program. At the same time, our international partners have also invested nearly \$4.7 billion in additional, complementary international Earth observation missions from which the U.S. will receive important data. Leveraging resources through partnerships promotes efficiency and avoids duplication of effort as organizations and countries around the world take on different parts of the global puzzle that is our Earth system. Even countries without space programs can contribute to the international effort through access to data and first-rate scientific analysis of research results. NASA is a leader in promoting greater cooperation and involvement. In addition to existing cooperative arrangements, NASA is at the forefront in the development of an integrated global observing strategy to coordinate data collection worldwide and to commit nations to the collection and sharing of environmental information. A broad-based research effort is indeed critical to the success of the NASA Earth Science program.

Cooperative efforts with other federal agencies combine science needs and operational requirements.

NASA is expanding its long partnership

with the National Oceanic and Atmospheric Administration (NOAA) to enhance operational weather capabilities and NASA is also broadening cooperation with NOAA and the U.S. Geological Survey (USGS) on critical land observations. NASA and NOAA are moving to more closely coordinate their activities in the area of Earth observations, with a focus on providing mutually beneficial services for a lower overall cost. The converged national weather satellite program among NASA, NOAA, and the Department of Defense (DoD) is an excellent example of this enhanced cooperation. NASA's technology has contributed directly to improvements in weather forecasting that have occurred since the 1960's, and NASA's critical role in this effort is to demonstrate advanced technology.

Commercial partnerships will yield more cost-effective solutions to science requirements while enhancing the relevance of scientific discovery.

NASA released the Earth Science Enterprise's Commercial Strategy last year, which is designed to drive down the cost of science data acquisition, exploit cutting-edge industry technologies and information systems, and to work with the commercial sector to develop new technologies which are mutually beneficial to government and business. To ensure that we are constantly pursuing the most cost-effective approach to acquiring needed observations, we conducted our first Biennial Review of program implementation last year. NASA will also continue to pursue partnerships with the private sector to encourage a thriving new industry which transforms data into practical applications that can be useful in the daily lives of everyday Americans and their businesses in areas such as agriculture, forestry, fishing, and mineral extraction.

What have we learned? **What** else will we learn?

The Earth Science Enterprise, in conjunction with the U.S. Global Change Research Program (USGCRP), follows an approach of characterizing, understanding, and predicting:

Characterizing

Providing satellite data to state and local planning authorities. Satellite images of the Earth's surface can be combined with aircraft photos and street utility maps in geographic information systems to provide planning authorities with the data they need to make multi-million dollar decisions on civil works.

Documenting success of international ozone treaties for protection of Earth's natural radiation shield. Researchers have been monitoring the concentration of ozone-depleting chemicals to determine the effectiveness of international treaties to protect the ozone layer. NASA and NOAA measurements indicate that the treaty is proving effective.

Understanding

Understanding the world's oceans and their effects on us. Satellite data challenged a fundamental theory about large scale waves in the oceans, a finding expected to revise textbooks and improve weather forecasting. We also continue to precisely measure changes in sea level, and its environmental and economic effects on our shorelines.

Measuring harmful Ultraviolet (UV) radiation. New analysis techniques for ozone data make it possible to provide the first global data set on surface ultraviolet radiation.

Predicting

Learning to predict regional seasonal and annual precipitation for agriculture. What farmer or rancher has not wished he could predict the amount and pattern of rainfall in the next growing season? Researchers have discovered that precipitation in the mid-latitudes is strongly influenced by a warming of Pacific Ocean waters called El Niño. By studying such phenomena, researchers hope to be able to provide regionally useful seasonal and annual forecasts in North America and elsewhere.

We are now entering an unprecedented period of spacecraft launch and research activities:

This year, EOS will begin providing the first integrated measurements of changes in the global climate. An ocean winds mission designed to collect wind-speed and wind direction is also scheduled for 1998. In 1999, the Earth Science Enterprise will demonstrate land-imaging technology as part of NASA's New Millennium Program. Also planned for 1999, a joint U.S./German Shuttle radar mission with the Department of Defense and the U.S. Geological Survey to generate the most precise map ever of most of the Earth's surface topography. In 2000, a successor to a highly accomplished U.S./French oceanography mission will be launched as well as a mission to study the distribution of forests and a follow-on U.S./Russian ozone monitoring mission.

NASA Facts

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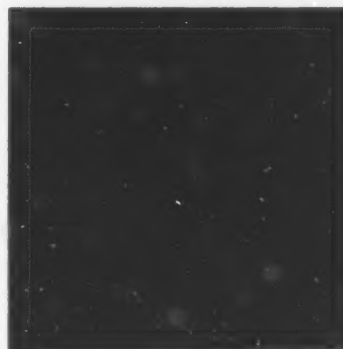
February 1998

How is the Earth's Surface Changing?

In many ways. Wind, rain, volcanoes, and continental shifts have always acted to change the Earth's surface. The 1980 eruption of Mt. St. Helens left 250 square miles of surrounding land damaged by the lateral blast. Human activity is a powerful force in its own right. About 35 percent of the world's land surface is used for farms and pastures. The Earth's population has nearly tripled since 1930, and is expected to double again over the next century. Currently, 45% of people live in urban areas; by 2025, 60% will be urban dwellers. Viewed from above, it is clear that the Earth's surface changes dynamically.

Satellite images are helping regional and city planners guide development in ways that minimize environmental impact. Forestry companies use remote sensing data to shape harvesting and replanting strategies to ensure the viability of their business and the health of forests for the next hundred years. Agribusiness is learning "precision agriculture" methods which conserve scarce soil and water resources. The challenge of achieving sustainable development is enormous, and the view from space is proving essential to the task.

NASA's role: The first civilian land imaging satellite experiment was launched by NASA in 1972 (before the Earth Science Enterprise era), beginning the widely used Landsat data set which continues with the launch of Landsat 7 this year. A new generation of land imaging sensors will also be launched this year as part of the Earth Observing System. The growing utility of land imagery has led to an emerging commercial market for these data, and NASA is pursuing innovative partnerships with commercial firms, both to acquire data and to create new information products. The view from space is complemented by scientific field campaigns in key regions of the world such as the Amazon rainforest.



These Landsat images of the state of Rondonia, Brazil were taken in 1975 (top) and 1986 (bottom). Areas where forest lands were converted to agricultural uses are identifiable as a fishbone pattern in the 1986 image. The contrast between the two images indicates the magnitude of the change that occurred in only 11 years.



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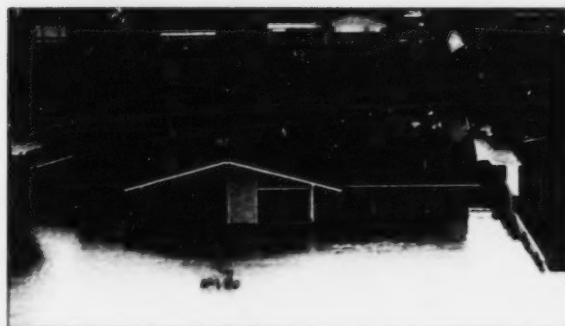


February 1998

How Does El Niño Affect Our Weather?

In many ways. El Niño is a climate disturbance that occurs every two to five years in the Pacific Ocean. A region of warm water forms in the western Pacific and moves toward South America. In doing so, it alters weather and rainfall patterns, wind directions and even the jet stream, in both the tropics and the northern latitudes of our hemisphere.

Though scientists still do not fully understand how it forms, they do believe that El Niño conditions may have contributed to the 1993 Mississippi and 1995 California floods, as well as to drought conditions in South America, Africa, and Australia. The 1993 El Niño event was responsible for \$8 billion in damages in 33 countries, and the 1997-98 El Niño may prove equally damaging.



NASA's role: A joint U.S./French satellite is providing the most precise measurements ever of El Niño's effect on the ocean surface and its progress as a "wave" across the Pacific. Based on these and other measurements, NASA and NOAA predicted this year's El Niño 6 months in advance. Additional study by NASA scientists and other researchers will enable us to understand the interactions between the ocean and the atmosphere during an El Niño, to more accurately predict how it will affect the weather, and perhaps to prepare for its occurrences. (Left image is derived from Topex/Poseidon data and right image represents a visualization of El Niño using the same data.)

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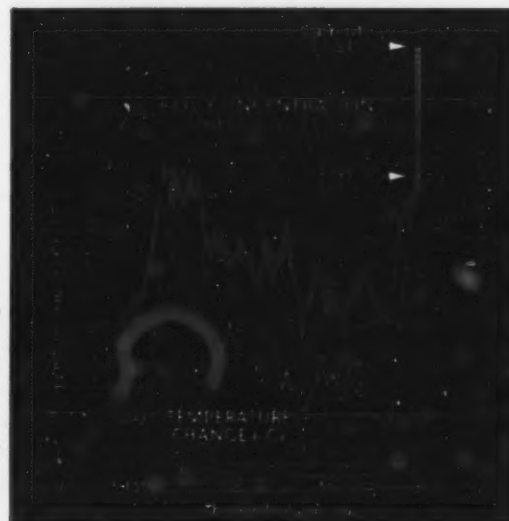
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Is the Earth Experiencing a Warming Trend?

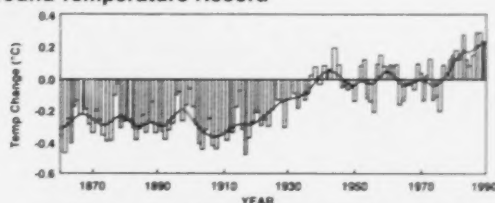
Computer models predict that it is. Burning coal, oil and natural gas to heat our homes, power our cars, and illuminate our cities produces carbon dioxide (CO₂) and other greenhouse gases as by-products. Deforestation and clearing of land for agriculture also release significant quantities of such gases. Over the last century, we have been emitting greenhouse gases to the atmosphere faster than natural processes can remove them. During this time, atmospheric levels of these gases have climbed steadily and are projected to continue their steep ascent as global economies grow.

Records of past climate going as far back as 160,000 years indicate a close correlation between the concentration of greenhouse gases in the atmosphere and global temperatures. Computer simulations of the climate indicate that global temperatures will rise as atmospheric concentrations of CO₂ increase. An international panel of 2,000 of the world's leading climate scientists concluded that Earth has already warmed about 1°F over the last century, and that "the balance of evidence suggests a discernible human influence on global climate."

Atmospheric Carbon Dioxide Concentration and Temperature Change

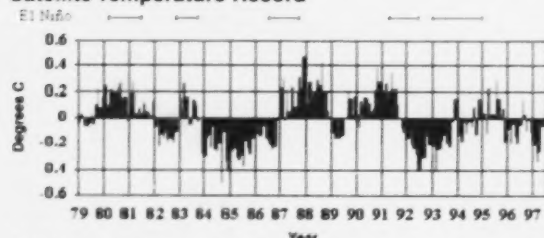


Ground Temperature Record



Global-mean combined land-air and sea-surface temperatures, 1861-1989, relative to the average for 1951-80.

Satellite Temperature Record



El Niño

Cooling from Pinatubo

Global Lower Tropospheric Temperatures 1979-97

This international panel estimates that global surface air temperature will increase another 2-6°F in the next 100 years. The difference in temperature from the last ice age to now is about 9°F. Their best guess is that we will experience warming of about 3.5°F by 2100, which would be a faster rate of climate change than any experienced during the last 10,000 years, the period in which modern civilization developed.

Warming of this magnitude will affect many aspects of our lives as it changes temperature and precipitation patterns, induces sea level rise, and alters the distribution of fresh water supplies. The impacts on our health, the vitality of forests and other natural areas, and the productivity of agriculture are all likely to be significant but not yet well understood. Only through a sustained effort of sound Earth Science research can these impacts be understood at the regional and global levels.

NASA's role: We are working with other agencies and nations to gather the scientific evidence to improve long-term climate models. Beginning this year, NASA is launching a series of satellites and airborne platforms—the Earth Observing System—designed to study how the different parts of the Earth's environment (air, water, land, and life) all interact, and resolving discrepancies between satellite and ground temperature records (see temperature charts on this page). This data will help us to better understand and predict how Earth's climate may be changing and what the effects could be.

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Will Sea Levels Rise?

Many scientists believe it will, but to what degree is unknown. Scientists believe that as we add carbon dioxide and other emissions to the atmosphere, the Earth will get warmer. If this happens, ocean levels will rise, because of melting ice and the expansion of ocean water as it warms. There is clear evidence of slowly rising sea levels over the last century.

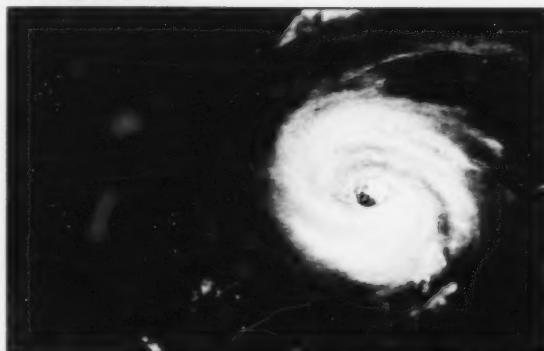
Rising sea level erodes beaches and coastal wetlands, inundates low-lying areas, and increases the vulnerability of coastal areas to flooding from storm surges and intense rainfall. By 2100, sea level is expected to rise by 6 to 37 inches. A 20-inch sea level rise will result in substantial loss of coastal land in the United States, especially along the southern Atlantic and Gulf coasts, which are subsiding and are particularly vulnerable. The oceans will continue to expand for several centuries after temperatures stabilize. Because of this, the sea level rise associated with CO₂ levels of 550 parts per million (ppm) (double pre-industrial levels) could eventually exceed 40 inches. A CO₂ level of 1100 ppm could produce a sea level rise of 80 inches or even more, depending on the extent to which the Greenland and Antarctic ice sheets melt.

A 20-inch sea level rise would double the global population at risk from storm surges, from roughly 45 million at present to over 90 million, and this figure does not account for any increases in coastal populations—more than half the U.S. population lives within 50 miles of a coastline. A 40-inch rise would triple the number. South Florida is highly vulnerable to sea level rise. A third of the Everglades has an elevation of less than 12 inches. Salt water intrusion would adversely affect delicate ecological communities and degrade the habitat for many species.

NASA's role: Using a radar altimeter, a U.S./French satellite is currently making very precise measurements of global sea height. Data show a small rise in sea level since 1992, though more information is needed to establish a trend. NASA is supporting a research program consisting of satellite, aircraft and surface measurements for documenting changes in the Greenland ice sheet. Also NASA, in collaboration with Canadian Space Agency completed data collection for producing first high-resolution radar maps of Antarctica. Over the next decade, all these data will help us tell whether ocean levels are rising and, perhaps, offer clues to the cause(s).



Hurricane Fran



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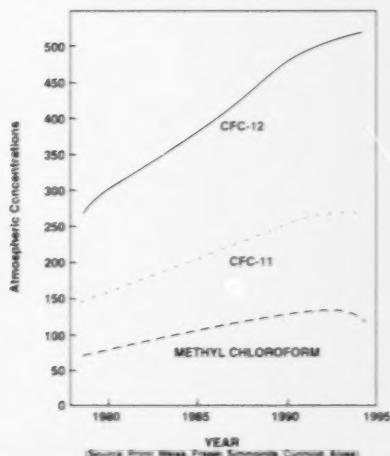
Is the Ozone Layer Still in Trouble?

Yes, but help is on the way. The ozone layer is a thin band in the upper atmosphere that blocks out most of the Sun's harmful ultraviolet rays. Without this protective shield, life on Earth would be impossible. The ozone layer has been damaged by chemicals (such as chlorofluorocarbons or CFCs) which are used in refrigerators, air conditioners, and industry.

Ozone in Earth's Atmosphere



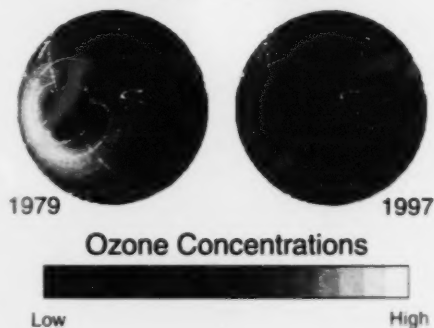
Global Average Concentrations for Ozone-Depleting Gases



NASA's role: Though ozone levels over Antarctica and the rest of the globe will continue to decline for several years, NASA and NOAA measurements have now detected evidence that the treaties to protect the ozone layer are beginning to work. Concentrations of ozone-depleting chemicals are beginning to level off or decrease. Continued monitoring by NASA and other agencies and further study will be needed to understand how CFC substitutes are affecting ozone levels.

NASA satellites, aircraft, balloon, and ground measurements helped detect the effects of CFCs on the ozone layer and enabled us to understand why they were occurring. One of these effects is the "ozone hole," an area of extreme ozone depletion that forms over Antarctica each spring (fall in the U.S.). As a result of this research - led by U.S. scientists, government, and industry - the nations of the world agreed to ban the production of CFCs by 1996.

Antarctic "Ozone Hole"



The Earth Science Enterprise Accomplishments

Discoveries and "Firsts"

WEATHER



NASA launched the first weather satellite (TIROS I) in 1960, beginning a successful series of spacecraft that revolutionized weather prediction as well as improved hurricane-tracking techniques and severe-storm warnings, thus protecting lives and property in coastal areas around the world. NASA continues to build all of the Nation's civilian weather satellites for the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service, and is working on new science and technologies designed to substantially improve forecasting in the future.

LAND USE



NASA pioneered studying the Earth's surface from space, spawning a growing commercial remote sensing sector. NASA-funded researchers are using satellite and ground data to help improve agricultural productivity and enable precision farming. They are using satellite and aircraft data to track the deterioration of wetlands in the Chesapeake Bay, speed the clean-up of hazardous waste sites, and forecast the potential for future flooding along the Mississippi River. In addition, NASA analysis of data from Landsat first proved that satellites could be used to accurately estimate tropical deforestation.

EARTHQUAKES



Two NASA/Italian satellites have helped scientists precisely track movements of the Earth's surface for nearly 20 years, increasing our understanding of earthquakes. NASA researchers developed low-cost ground receivers of data from the Global Positioning System that enable precise determination of land motion, another key in understanding seismic activity. NASA is working with state and federal agencies to install a network of these receivers in the Los Angeles Basin to precisely measure surface motion.

OCEANS



NASA ocean research provided the first precise measurements of sea level and ocean circulation to date. Data from a U.S./French satellite were used to track the progress of the 1997 El Niño, the latest episode of the climate shift that can bring devastating rains to California and drought to Australia and Africa. In the future, these data will help us predict how El Niño will affect different parts of the world. From 1978-86, a NASA instrument provided the first global measurements of plant life in the world's oceans, important to understanding both how climate may be changing and where fish are gathering; this data set resumed last year.

OZONE



A NASA satellite confirmed the existence of the Antarctic ozone hole in 1985 and has monitored its size since then. Data from NASA aircraft, balloons, satellites, and ground research helped confirm the link between human-produced chemicals and ozone destruction, and a recent analysis of NASA data shows levels of ultraviolet radiation reaching the surface have risen. This research contributed significantly to the international treaties signed to protect the ozone layer. Now, NASA and NOAA measurements indicate that the treaties are beginning to work.

Earth

The Earth Science Enterprise Accomplishments

Data and Research

OPEN ACCESS



NASA led the government effort to establish an open access policy for the data from environmental research. This means that all data from government-funded research satellites are being processed as quickly as possible and made readily available for wide use. The prototype (Version 0) of the Earth Science Enterprise's data system—called EOSDIS—went on line in 1994 to allow scientists from around the world to work with existing data sets, and to provide feedback to designers on how the system could evolve and be even more useful. Tens of thousands of individuals use the system each month, many of them via the Internet.

BROAD USE



EOSDIS will be one of the largest civilian data systems ever constructed. While a prime role is to support the Earth Science Enterprise's researchers, a wide range of customers will use data from EOSDIS. When fully operational, NASA estimates that the system will serve:

- ◆ thousands of Earth scientists, in the U.S. and across the globe;
- ◆ up to 10,000 other researchers, government officials, etc.; and
- ◆ over 100,000 users in business, education, agriculture, media, and the public.

Preparing for the Future

EDUCATION & TRAINING



NASA is helping to train the next generation of scientists and engineers to understand and study Earth as an integrated system, and working with educators as research evolves and capabilities change. As of 1997, the Earth Science Enterprise has:

- ◆ helped develop an international science and education program—called GLOBE—in which hundreds of thousands of U.S. and international students are making local measurements and pooling their data through the Internet;
- ◆ supported nearly four dozen universities to develop college courses (introductory and upper level) in Earth System Science - thousands of students have already benefited;
- ◆ awarded nearly 400 global change and Earth Science fellowships since 1989;
- ◆ educated teachers at 2,500 U.S. sites about NASA's Earth science findings through NASA's live education videoconference series;
- ◆ supported over two dozen universities to develop new courses in Earth system science to be taught to future teachers in the colleges of education;
- ◆ developed an Internet-based graduate level Earth System Science teacher training course to reach and train teachers all across the nation;
- ◆ trained over 7000 teachers across the nation on selected Earth Science educational products;
- ◆ sponsored a program of "ground truth" studies involving over 1000 teachers (and their classes) from 38 states and four countries since 1991; and
- ◆ led development of a government-wide effort to coordinate Earth science education efforts, including extensive cooperation with teams of educators and officials from nearly every state in the U.S. and education grants to more than half of them.

Facts

The Earth Science Enterprise Researchers

Q: **Who are they?**

A: There are 1263 Research and Analysis investigators as well as 809 Earth Observing System investigators which totals 2072 Earth Science Enterprise Researchers

Q: **Where are they from?**

A: 1872 U.S. researchers from nearly every state, the District of Columbia and Puerto Rico

- ◆ Over half from universities/colleges
- ◆ About a third from 6 NASA installations
- ◆ Remainder from private research centers and more than a dozen other government agencies

200 researchers from 14 other nations and they are funded by their respective countries

Q: **What about the future?**

A: *NASA directly has awarded:*

- 401 Global change graduate fellowships between 1990 and 1998 (from 34 states and Puerto Rico)
- 90 NASA graduate research fellows (Earth science) between 1989 and 1998 (from 20 states)

NASA also supports:

Education and training of thousands of graduate students assisting NASA-funded researchers at universities and laboratories across the U.S., developing the foundation for environmental research into the next century.

Q: **What do they do?**

- A:
- ◆ Work on more than 2000 research tasks, in nearly a dozen research areas;
 - ◆ help develop more than two dozen instruments for space flight over the next decade, and participate on 73 interdisciplinary science teams;
 - ◆ lead and contribute to major international scientific assessments, including those examining the climate, forests, and pollution; and
 - ◆ produce upwards of 800 scientific papers annually on the results of their research.

How is NASA using innovation to enhance science capability?

NASA's program has a sound foundation in competitive, peer-reviewed science.

- ◆ NASA is focused on seasonal-to-interannual climate variations, land cover, natural hazards, and ozone changes, as well as long-term climate prediction. 9 external studies and numerous internal reviews have been conducted over the last 14 years which have validated our approach, including a major review by the National Academy of Sciences in 1995-96.

NASA's approach to the Earth Science Enterprise is focused on the future.

- ◆ Our plan for scientific evolution moves away from the old approach of large instruments reflight as exact copies. NASA conducted the first Biennial Review of the Earth Sciences Enterprise in early 1997 and one is scheduled every two years thereafter. These reviews are designed to provide continuous program innovation in a comprehensive, orderly fashion involving our scientific, commercial, and international partners.
- ◆ Technological changes and new partnerships will decrease our future costs by 30%—saving billions of taxpayer funds. We are testing a new approach to generate and distribute data.

Innovation and technology infusion increase our ability to get results.

- ◆ NASA is investing in the New Millennium Program (NMP) now to demonstrate advanced instruments and save costs of future missions. NMP is a cooperative NASA/private industry/university activity demonstrating next generation technology using lightweight, low-cost instruments.

- ◆ Earth System Science Pathfinders (ESSP) enable future science missions using low cost, cutting-edge small satellites under \$120M with a 24-36 month development time. Two missions have been selected for ESSP: one will study the distribution of forests (2000) and the other will explore the variability of Earth's gravity field (2001). ESSP will complement EOS with rapid development science to explore new areas of understanding.

NASA depends on growing commercial, international, and interagency partnerships.

- ◆ NASA is committed to purchasing data commercially now and in the future. Orbcomm-2 (formerly SeaStar) was launched last year, and NASA will complete two phases of a \$50 million scientific data purchase this year. The Commercial Strategy for the Earth Science Enterprise is promoting data applications, development of partnerships in data analysis, and advancement in technical development.
- ◆ NASA is closely working with NOAA/DoD on a next-generation weather satellite.
- ◆ Our international partners are investing \$4.0 billion in the Earth Science Enterprise and another \$4.7 billion in complementary missions for a total roughly equivalent to the U.S. investment in the Earth Science Enterprise.
- ◆ New decision strategy strives to expand international cooperation and increase cost sharing.

The pace of change in space technology has accelerated since the end of the Cold War, and we plan to take maximum advantage of these changes.

Earth Science Enterprise: *Program Description*

NASA's Earth Science Enterprise seeks to improve our understanding of the complex interactions of Earth's environment, and how it is changing. Spacecraft now in orbit and those to be launched through 1997 make measurements of specific aspects of the Earth. This year, EOS satellites will provide the first long-term, integrated observations of the global environment. These observations will help scientists understand how the Earth's land, air, water, and life interact, and eventually should enable scientists to predict how the Earth's climate will change, rather than just describing its features. EOS funding requirements through 2000 have been reduced by 60% since original approval by Congress in 1990, though NASA has maintained the most important science and program capabilities.

Getting information to people: The EOS Data and Information System (EOSDIS)

EOSDIS is an integrated data system which provides users with access to data and information from NASA's Earth observation missions. EOSDIS is specifically designed to evolve and adapt to changes (in user applications, technology, and requirements) so as to best serve all current and prospective users (defined and undefined).

EOSDIS is also a distributed system, with a central architecture (EOSDIS Core System) and a set of interconnected data centers across the U.S., each focusing on the processing, storage, and distribution of a different type of data about the Earth. The Earth Science Enterprise is pursuing a federated approach to EOSDIS data product generation which will open up opportunities to a broad range of industry, academic, and government partnerships to produce both planned and innovative data products.

Earth Science Enterprise budget information

The largest budget element for the Earth Science Enterprise is EOS. Through 2000, NASA estimates the total cost of EOS will be approximately \$6.5 billion. Post-2000, NASA has reduced estimated EOS costs by 30% through a strategy of technology infusion and interagency, international, and commercial cooperation.

FY 1998 approved funding and FY 1999 request (dollars in millions)

Program Element	FY 1998 Approved	FY 1999 Request
Earth Observing System (flight segment, including Landsat) <i>Technology Infusion</i>	704.6 [93.1]	659.1 [78.2]
EOS Data and Information System (EOSDIS)	209.9	256.6
Applied Research and Data Analysis <i>Science Grants</i>	364.4 [294.1]	365.4 [294.9]
<i>Operations, Data Retrieval, and Storage</i>	[70.5]	[70.5]
Earth Probes (TOMS, NSCAT, TRMM) <i>Earth System Science Pathfinders</i>	48.6 [33.9]	85.9 [70.0]
Launch Services	34.8	-----
GLOBE	5.0	5.0
TOTAL EARTH SCIENCE ENTERPRISE BUDGET	1367.3	1372.0

Earth Science Enterprise: *Mission Description*

Primary Missions Through 1997

Mission (with planned launch date)	Area of Study
Total Ozone Mapping Spectrometer (TOMS) - 1978, 1991, 1996, 2000	Ozone measurements (cooperative efforts with Russia & Japan)
Earth Radiation Budget Satellite (ERBS) - 1984	Radiation budget, aerosols, ozone
Upper Atmosphere Research Satellite (UARS) - 1991	Upper atmospheric chemistry (with UK & Canada)
ATLAS series - 1992-94	Shuttle experiments on the atmosphere and effects of the Sun (with Germany, Belgium, & France)
TOPEX/Poseidon - 1992	Ocean circulation (with France)
LAGEOS-2 - 1992	Crustal motion & Earth rotation (with Italy)
Space Radar Laboratory 1&2 missions - 1994	Synthetic aperture radar scans of the Earth's surface to classify vegetation and penetrate loose ground cover (with Germany and Italy)
Optical Transient Detector (OTD) - 1995	Lightning tracking experiment (with commercial firm)
NASA Scatterometer (NSCAT) - 1996	Ocean surface wind speed & direction (with Japan)
ORBCOMM-2 (SeaWiFS) - 1997	Ocean biological productivity (data purchase)
Tropical Rainfall Measuring Mission (TRMM) - 1997	Tropical rainfall and storms (with Japan)

The Earth Observing System (measurement groupings)

Mission (with planned first launch date)	Area of Study
EOS AM Series - 1998	Atmospheric/surface/solar processes controlling fresh water resources and ecological processes affecting global climate (with Japan and Canada)
Landsat-7 - 1998	Land surface features & changes (high resolution) (with USGS and NOAA)
EOS ACRIM Flights - 1999	Changes in total solar output (partner TBD)
QuikScat / SeaWinds - 1998, 2000	Role of oceans and ocean winds in climate system and interaction with atmosphere (with Japan and France)
Jason 1 Radar Altimetry Mission - 2001	Causes of climate variations and basis for improvements in long- term weather & climate prediction (with Japan and Brazil)
EOS PM Series - 2000	Ice sheet topography mapping
EOS Laser Altimetry Mission (ICESAT) - 2001	Behavior of ozone, other greenhouse gases; aerosols and their impact on global climate; as well as regional and global studies of pollution (with Japan, U.K. and Russia)
EOS Chemistry Series - 2002 / SAGE - 1999, 2001	Changes in ultraviolet radiation output from the Sun
EOS SOLSTICE Flights - 2002	

Complementary Missions Through 2002

Mission (with planned first launch date)	Area of Study
New Millennium Program missions - 1999/2001/2002	Technology demonstration missions for advanced instruments to reduce the cost of the next EOS series.
Earth System Science Pathfinder missions - 2000/2001/2002	Small satellites for new science measurements; low-cost, rapid development missions using innovative academia/industry partnerships
Shuttle Radar Topography Mission - 2000	Shuttle-based synthetic aperture radar flight to produce precise digital elevation models of most of the Earth's surface; partnership with DoD and USGS

Earth Science Enterprise: *Educational Resources*

For more information about the Earth Science Enterprise, please access the Internet sites and addresses listed inside the front cover. For general educational resources, please consult the list below, which is organized alphabetically by state. In addition, NASA has established the Central Operation of Resources for Educators (CORE) to provide the national and international distribution of NASA-produced educational materials in audiovisual format. Among

available items is the *EOS Educators' Visual Materials* package. For more information, contact:

NASA CORE
Lorain County Joint Vocational School
15181 Route 58 South
Oberlin, OH 44074
Phone: (216) 774-1051, Ext. 293 or 294
Fax: (216) 774-2144
E-mail: nasaco@leeca8.leeca.ohio.gov

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Moffett Field, CA 94035-1000
415/604-3574

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805/258-3456

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Maple High School
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One Carob Street
Lompoc, CA 93437
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Philadelphia, MS 39350
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